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The U.S. biogas experience in the 1970s and 1980s has demonstrated that biogas technology is not applicable for all farms. In many situations however, it can be a cost-effective and environmentally friendly method for treating manure and liquid waste. Biogas production is best suited for farms that handle large amounts of manure as a liquid, slurry, or semi-solid with little or no bedding added. Biogas systems require a financial investment and a management responsibility. The system must be designed by an experienced animal waste digester designer, who is well versed with the common problems associated with these types of systems. Additionally, the farm owner or operator must be committed to the digester's success.

This chapter provides an overview of biogas technology and opportunities to use this technology in livestock facilities across the United States. First, a brief description of biogas technology is provided. Then the benefits of biogas technology are discussed. Finally, the experience and status of biogas technology development in the United States are described.

1-1. What are the Components of a Biogas System?

Biogas technology is a manure management tool that promotes the recovery and use of biogas as energy by adapting manure management practices to collect biogas. The biogas can be used as a fuel source to generate electricity for on-farm use or for sale to the electrical grid, or for heating or cooling needs. The biologically stabilized byproducts of anaerobic digestion can be used in a number of ways, depending on local needs and resources. Successful byproduct applications include use as a crop fertilizer, bedding, and as aquaculture supplements.

A typical biogas system consists of the following components:

- ◆ Manure collection
- ◆ Anaerobic digester
- ◆ Effluent storage
- ◆ Gas handling
- ◆ Gas use.

Each of these components is discussed briefly.

1-1.1 Manure Collection

Livestock facilities use manure management systems to collect and store manure because of sanitary, environmental, and farm operational considerations. Manure is collected and stored as either liquids, slurries, semi-solids, or solids.

- ◆ **Raw Manure.** Manure is excreted with a solids content of 8 to 25 percent, depending upon animal type. It can be diluted by various process waters or thickened by air drying or by adding bedding materials.
- ◆ **Liquid Manure.** Manure handled as a liquid has been diluted to a solids content of less than 5 percent. This manure is typically “flushed” from where it is excreted, using fresh or recycled water. The manure and flush water can be pumped to treatment and storage tanks, ponds, lagoons, or other suitable structures before land application. Liquid manure systems may be adapted for biogas production and energy recovery in “warm” climates. In colder climates, biogas recovery can be used, but is usually limited to gas flaring for odor control.
- ◆ **Slurry Manure.** Manure handled as a slurry has been diluted to a solids content of about 5 to 10 percent. Slurry manure is usually collected by a mechanical “scraper” system. This manure can be pumped, and is often treated or stored in tanks, ponds, or lagoons prior to land application. Some amount of water is generally mixed

with the manure to create a slurry. For example, spilled drinking water mixes with pig manure to create a slurry. Manure managed in this manner may be used for biogas recovery and energy production, depending on climate and dilution factors.

- ◆ **Semi-Solid Manure.** Manure handled as a semi-solid has a solids content of 10 to 20 percent. This manure is typically scraped. Water is not added to the manure, and the manure is typically stored until it is spread on local fields. Fresh scraped manure (less than one week old) can be used for biogas and energy production in all climates, because it can be heated to promote bacterial growth.
- ◆ **Solid Manure.** Manure with a solids content of greater than 20 percent is handled as a solid by a scoop loader. Aged solid manure or manure that is left “unmanaged” (i.e., is left in the pasture where it is deposited by the animals) or allowed to dry is not suitable for biogas recovery.

1-1.2 Digester Types

The digester is the component of the manure management system that optimizes naturally occurring anaerobic bacteria to decompose and treat the manure while producing biogas. Digesters are covered with an air-tight impermeable cover to trap the biogas for on-farm energy use. The choice of which digester to use is driven by the existing (or planned) manure handling system at the facility. The digester must be designed to operate as part of the facility's operations. One of three basic options will generally be suitable for most conditions. Appendix F contains several NRCS Conservation Practice Standards for digesters. Exhibit 1-1 summarizes the main characteristics of these digester technologies:

- ◆ **Covered Lagoon Digester.** Covered lagoons are used to treat and produce biogas from liquid manure with less than 3 percent solids. Generally, large lagoon volumes are required, preferably with depths greater than 12 feet. The typical volume of the required lagoon can be roughly estimated by multiplying the daily manure flush volume by 40 to 60 days. Covered

Exhibit 1-1 Summary Characteristics of Digester Technologies

Characteristics	Covered Lagoon	Complete Mix Digester	Plug Flow Digester	Fixed Film
Digestion Vessel	Deep Lagoon	Round/Square In/Above-Ground Tank	Rectangular In-Ground Tank	Above Ground Tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	0.5 - 3%	3 - 10%	11 - 13%	3%
Solids Characteristics	Fine	Coarse	Coarse	Very Fine
HRT* (days)	40 - 60	15+	15+	2-3
Farm Type	Dairy, Hog	Dairy, Hog	Dairy Only	Dairy, Hog
Optimum Location	Temperate and Warm Climates	All Climates	All Climates	Temperate and Warm

* Hydraulic Retention Time (HRT) is the average number of days a volume of manure remains in the digester.

lagoons for energy recovery are compatible with flush manure systems in warm climates. Covered lagoons may be used in cold climates for seasonal biogas recovery and odor control (gas flaring). There are two types of covers, bank-to-bank and modular. A bank-to-bank cover is used in moderate to heavy rainfall regions. A modular cover is used for arid regions. Exhibit 1-2 illustrates a modular floating cover for lagoon applications. Typically, multiple modules cover the lagoon surface and can be fabricated from various materials.

◆ **Complete Mix Digester.** Complete mix digesters are engineered tanks, above or below ground, that treat slurry manure with a solids concentration in the range of 3 to 10 percent. These structures require less land than lagoons and are heated. Complete mix digesters are compatible with combinations of scraped and flushed manure.

◆ **Plug Flow Digester:** Plug flow digesters are engineered, heated, rectangular tanks that treat scraped *dairy* manure with a range of 11 to

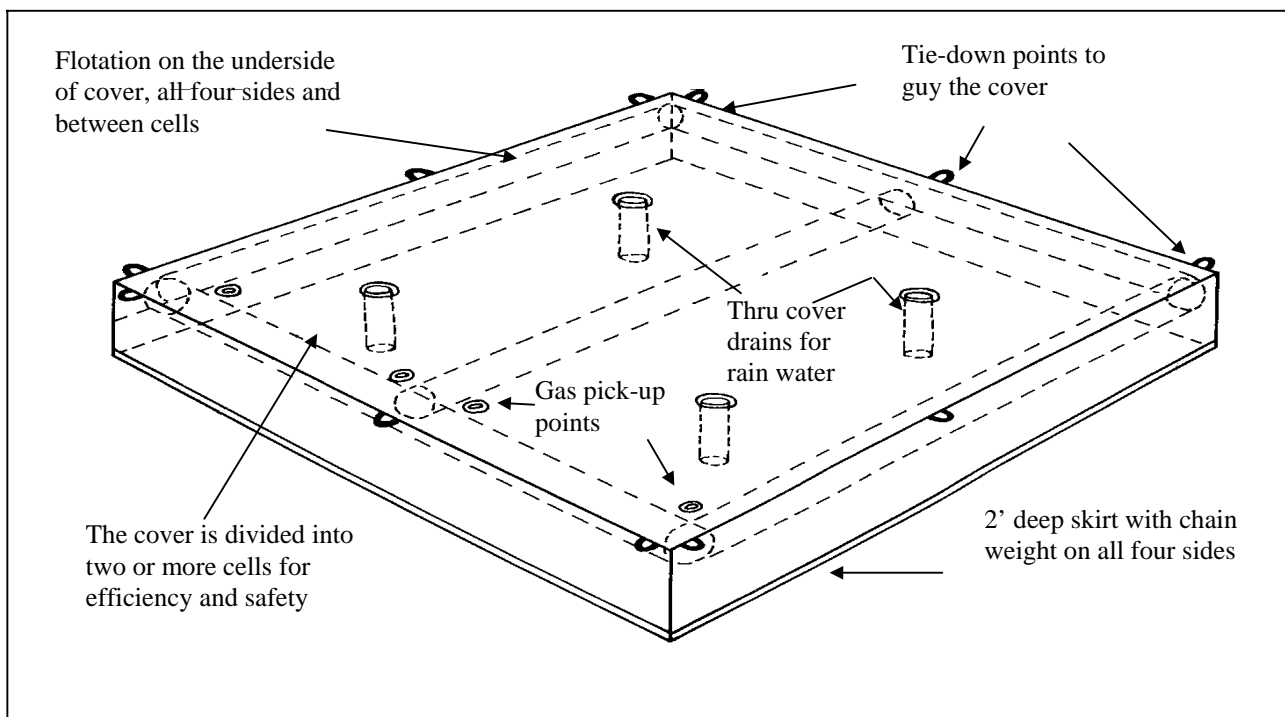
13 percent total solids. Swine manure cannot be treated with a plug flow digester due to its lack of fiber.

◆ **Fixed Film Digester.** Fixed-film digesters consist of a tank filled with plastic media. The media supports a thin layer of anaerobic bacteria called biofilm (hence the term "fixed-film"). As the waste manure passes through the media, biogas is produced. Like covered lagoon digesters fixed-film digesters are best suited for dilute waste streams typically associated with flush manure handling or pit recharge manure collection. Fixed-film digesters can be used for both dairy and swine wastes. However, separation of dairy manure is required to remove slowly degradable solids.

1-1.3 Effluent Storage

The products of the anaerobic digestion of manure in digesters are biogas and effluent. The effluent is a stabilized organic solution that has value as a fer-

Exhibit 1-2 Floating Cover Module for Lagoon Application in Arid Regions



Courtesy of Engineered Textile Products, Inc.

tilizer and other potential uses. Waste storage facilities are required to store treated effluent because the nutrients in the effluent cannot be applied to land and crops year round.

The size of the storage facility and storage period must be adequate to meet farm requirements during the non-growing season. Facilities with longer storage periods allow flexibility in managing the waste to accommodate weather changes, equipment availability and breakdown, and overall operation management.

1-1.4 Gas Handling

A gas handling system removes biogas from the digester and transports it to the end-use, such as an engine or flange. Gas handling includes: piping; gas pump or blower; gas meter; pressure regulator; and condensate drain(s).

Biogas produced in the digester is trapped under an airtight cover placed over the digester. The biogas is removed by pulling a slight vacuum on the collection pipe (e.g., by connecting a gas pump/blower to the end of the pipe), which draws the collected gas from under the cover. A gas meter is used to monitor the gas flow rate. Sometimes a gas scrubber is needed to clean or “scrub” the biogas of corrosive compounds contained in the biogas (e.g., hydrogen sulfide). Warm biogas cools as it travels through the piping and water vapor in the gas condenses. A condensate drain(s) removes the condensate produced.

1-1.5 Gas Use

Recovered biogas can be utilized in a variety of ways. The recovered gas is 60 - 80 percent methane, with a heating value of approximately 600 - 800 Btu/ft³. Gas of this quality can be used to generate electricity; it may be used as fuel for a boiler, space heater, or refrigeration equipment; or it may be directly combusted as a cooking and lighting fuel. Chapter 3 provides more information on biogas use.

Electricity can be generated for on-farm use or for sale to the local electric power grid. The most common technology for generating electricity is an internal combustion engine with a generator. The predicted gas flow rate and the operating plan are

used to size the electricity generation equipment.

Engine-generator sets are available in many sizes. Some brands have a long history of reliable operation when fueled by biogas. Electricity generated in this manner can replace energy purchased from the local utility, or can be sold directly to the local electricity supply system. In addition, waste heat from these engines can provide heating or hot water for farm use.

Biogas can also be used directly on-site as a fuel for facility operations. Equipment that normally uses propane or natural gas can be modified to use biogas. Such equipment includes boilers, heaters, and chillers.

◆ **Boilers and Space Heaters.** Boilers and space heaters fired with biogas produce heat for use in the facility operations. Although this may not be the most efficient use of the gas, in some situations it may be a farm’s best option.

◆ **Chilling/Refrigeration.** Dairy farms use considerable amounts of energy for refrigeration. Approximately 15 to 30 percent of a dairy’s electricity load is used to cool milk. Gas-fired chillers are commercially available and can be used for this purpose. For some dairies, this may be the most cost effective option for biogas utilization.

Other energy use options may exist. For example, a nearby greenhouse could be heated with the biogas, and carbon dioxide from the heater exhaust could be used to enhance plant growth. These options need to be evaluated on a case-by-case basis.

1-2. Benefits of Biogas Technology

Most confined livestock operations handle manure as liquids, slurries, semi-solids, or solids that are stored in lagoons, concrete basins, tanks, and other containment structures. These structures are typically designed to comply with local and state environmental regulations and are a necessary cost of production.

Biogas technology can be a cost-effective, environment and neighborhood friendly addition to existing

manure management strategies. Biogas technologies anaerobically digest manure, resulting in biogas and a liquefied, low-odor effluent. By managing the anaerobic digestion of manure, biogas technologies significantly reduce Biochemical Oxygen Demand (BOD), and pathogen levels; remove most noxious odors; and convert most of the organic nitrogen to plant available inorganic nitrogen.

The principal reasons a farmer or producer would consider installing a biogas system are:

- ◆ **On-Site Farm Energy.** By recovering biogas and producing on-farm energy, livestock producers can reduce monthly energy purchases from electric and gas suppliers.
- ◆ **Reduced Odors.** Biogas systems reduce offensive odors from overloaded or improperly managed manure storage facilities. These odors impair air quality and may be a nuisance to nearby communities. Biogas systems reduce these offensive odors because the volatile organic acids, the odor causing compounds, are consumed by biogas producing bacteria.
- ◆ **High Quality Fertilizer.** In the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium. Ammonium is the primary constituent of commercial fertilizer, which is readily available and utilized by plants.
- ◆ **Reduced Surface and Groundwater Contamination.** Digester effluent is a more uniform and predictable product than untreated manure. The higher ammonium content allows better crop utilization and the physical properties allow easier land application. Properly applied, digester effluent reduces the likelihood of surface or groundwater pollution.
- ◆ **Pathogen Reduction.** Heated digesters reduce pathogen populations dramatically in a few days. Lagoon digesters isolate pathogens and allow pathogen kill and die-off prior to entering storage for land application.

Biogas recovery can improve profitability while improving environmental quality. Maximizing farm resources in such a manner may prove essential to

remain competitive and environmentally sustainable in today's livestock industry. In addition, more widespread use of biogas technology will create jobs related to the design, operation, and manufacture of energy recovery systems and lead to the advancement of U.S. agribusiness.

1-3. The U.S. Biogas Experience

Rising oil prices in the 1970's triggered an interest in developing "commercial farm-scale" biogas systems in the United States. During this developmental period (1975-1990) approximately 140 biogas systems were installed in the United States, of which about 71 were installed at commercial swine, dairy, and caged layer farms.

Many of these initial biogas systems failed. However, learning from failures is part of the technology development process. Examining past failures and successes led to improvements and refinements in existing technologies and newer, more practical systems. The main reasons for the success and failure of biogas recovery projects follow.

1-3.1 Reasons for Success

Biogas recovery projects succeeded because:

1. The owner/operator realized the benefits biogas technology had to offer and wanted to make it work.
2. The owner/operator had some mechanical knowledge and ability and had access to technical support.
3. The designer/builder built systems that were compatible with farm operation.
4. The owner/operator increased the profitability of biogas systems through the utilization and sale of manure byproducts. Some facilities generate more revenues from the sale of electricity and other manure byproducts than from the sale of milk.

1-3.2 Reasons for Failure

Biogas recovery projects failed because:

1. Operators did not have the skills or the time required to keep a marginal system operating.
2. Producers selected digester systems that were not compatible with their manure handling methods.
3. Some designer/builders sold “cookie cutter” designs to farms. For example, of the 30 plug flow digesters built, 19 were built by one designer and 90 percent failed.
4. The designer/builders installed the wrong type of equipment, such as incorrectly sized engine-generators, gas transmission equipment, and electrical relays.
5. The systems became too expensive to maintain and repair because of poor system design.
6. Farmers did not receive adequate training and technical support for their systems.
7. There were no financial returns of the system or returns diminished over time.
8. Farms went out of business due to non-digester factors.

This handbook draws from these lessons and provides a realistic screening process for livestock facilities to decide if biogas technology is an appropriate match for the farm and farm owner.

1-3.3 Today’s Experiences

The development of anaerobic digesters for livestock manure treatment and energy production has accelerated at a very fast pace over the past few years. Factors influencing this market demand include: increased technical reliability of anaerobic digesters through the deployment of successful operating systems over the past decade; growing concern of farm owners about environmental quality; an increasing number of states and federal programs designed to cost share in the development of these systems; and the emergence of new state

energy policies designed to expand growth in reliable renewable energy and green power markets.

There are currently about 70 operating digester systems, with another 35 planned for construction in 2004. Six of these centralized systems provide manure treatment for surrounding farms. Currently, three centralized systems are operational and three more are planned. A methodology for assessing and reviewing centralized projects is discussed further in Chapter 9. More information on some of the operating digesters can be found in Appendix A.